

Report No. UT-02.14

***PHASE II: SEISMIC
REHABILITATION OF
CONCRETE BRIDGES-
VERIFICATION USING IN-
SITU TESTS AT SOUTH
TEMPLE BRIDGE ON I-15***

Construction Report

**By: Chris Pantelides, Ph.D, P.E.
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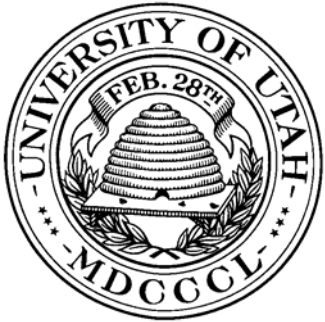
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Salt Lake City, Utah**

**Utah Department of Transportation
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UDOT RESEARCH & DEVELOPMENT REPORT ABSTRACT

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16. Abstract The reconstruction of the Interstate 15 corridor provided a unique opportunity to test bridge structures in-situ in the as-built condition before demolition. The tests were carried out in the summer of 1998 (Phase I) and the summer of 2000 (Phase II). The present report refers to the tests that were carried out during Phase II in 2000. The report contains information on all aspects of the application of the FRP composite retrofit for Bent No. 6 of the Southbound lanes of the South Temple Bridge on I-15. The report includes only the construction aspects of the test for Bent No. 6. A full description of the tests results of the test of Bent No. 6 as well as Bents No. 4 and No. 5 that were tested in Phase II is presented in another report. The present report includes a description of the condition of Bent No. 6, labor analysis, material analysis, materials usage, tools used, and the procedures for retrofitting Bent No. 6 with FRP composites.					
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**Report to Sponsors:
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FORWARD

University of Utah Professors Chris P. Pantelides and Lawrence D. Reaveley obtained a research grant from the Utah Department of Transportation (UDOT) for performing a research study regarding the evaluation of capacity and seismic retrofit of three reinforced concrete systems, consisting of a three column bent without a deck and two three-column bents joined by the existing deck. The Southbound lanes of the South Temple Bridge, at Interstate 15 was the site for performing these tests. The tests were performed in April and May of 2000. Two of the bents were retrofitted with a grade beam at the foundation level and the third was also retrofitted with a grade beam but in addition it was reinforced with carbon fiber reinforced polymer (FRP) composites.

Principal investigator for the project was Professor Chris P. Pantelides, and co-principal investigator was Professor Lawrence D. Reaveley of the Department of Civil and Environmental Engineering. Mr. Jeffrey B. Duffin, Mr. Jon Ward, and Mr. Chris Delahunty, graduate students at the Civil and Environmental Engineering Department, were the research assistants for the project.

Dr. Larry Cercone of Air Logistics Corporation assisted in the application of the FRP composite and the compilation of this report.

This document constitutes the Construction Report for the project. The UDOT managers for the project were Mr. Samuel Musser, P.E., Research Program Manager, and Dan Avila, P.E., Senior Research Project Manager, of the UDOT Research Division.

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Finally, the authors would like to thank Wasatch Constructors, Sika Corporation, and Hydrotech for their assistance in the project.

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INTRODUCTION

The present report details the construction sequence and installation on I-15 Bridge No. 58, Bent No. 6 at South Temple in Salt Lake City, UT. The bridge was corroded in the bent caps due to various environmental factors such as freeze-thaw cycles and needed repair both for environmental degradation and seismic upgrade. This was a unique opportunity for the University of Utah to test carbon FRP composite technology since the I-15 reconstruction led to testing existing bridges before demolition and replacement.

The application of the FRP composite was performed by Sika Corporation with the assistance of students from the University of Utah, and Dr. Larry Cercone of Air Logistics Corporation. This project is the second of a series of tests that were carried out at this site. The first test was carried out in 1998, and the current test in 2000.

Sika Corporation recommended their handwrap system that consists of the carbon fabric, adhesive, and resin systems. The combination of these along with sealing out moisture, chlorides, and repairing active corrosion damage increases the bridge column strength during an earthquake and extends the life of the structure.

The University of Utah proposed that in-situ tests be carried out before and after retrofit with FRP composites, to determine if the retrofit works. The test program included three bents: bent 4, bent 5, and bent 6. Bent 6 was retrofitted with carbon FRP composites and was expected to provide data for calibrating analytical models and design procedures for seismic retrofit of similar reinforced concrete bridges with FRP composites.

The present report includes only the construction aspects of the test for Bent No. 6. A full description of the test results on the three bents is presented by the University of Utah in another report.

1. Interstate 15 South Temple Bridge Bent No. 6

Sika Corporation with the assistance of students from the Civil Engineering Department of the University of Utah, and Dr. Larry Cercone of Air Logistics Corporation retrofitted Bent No. 6 of the South Temple Bridge located in Salt Lake City, Utah. The bridge consisted of the southbound lanes of the South Temple Street Overpass on Interstate 15. The bridge has 8 bents and 9 spans. The tests required the use of Bent No. 6. The reason for choosing this bent is the convenient location, especially the distance from the railroad tracks.

Sika Corporation retrofitted the three square columns and cap beam on Bent No. 6. The columns were 3' x 3' x 24' (0.91m x 0.91m x 7.32m) from the footing and the cap beam cross-section was 36" x 48" (0.91m x 1.22m). The cap beam was 64.5 feet long (19.67m). This report starts with details of the initial condition of the bridge. The detailed design, materials used, cost of materials, tooling and procedure are included later in this report. Figure 1 shows Bent No. 6 and the scaffolding used in the retrofit operation.



Figure 1. Bridge No. 58 Bent No. 6 Southbound I-15 at South Temple

2. Condition of Bent No. 6 of Southbound Lanes at South Temple Bridge

This bridge bent had large cracks and holes in the concrete beam cap and column in the areas to be retrofitted. Concrete had spalled off leaving holes approximately 1' x 4' (0.31m x 1.22m) at the corners. Rebar was exposed on the cap beam as shown in Figure 2. Shotcrete was applied to restore the cap to its original dimensions after all loose concrete was removed with water blast.

All of the corners had to be rounded during the retrofit. Shotcrete on the I-beams had to be rounded off also. Column surfaces had to be cleaned prior to any material being applied. This step can be speeded up if the surface is water washed prior to the retrofit work. Of most importance are the first few inches on the column above the footing.



Figure 2. Cap Beam Showing Exposed Rebar and Spalled Concrete

The condition of the cap beam after it was repaired with shotcrete is shown in Figure 3. This operation is necessary to bring the cap beam back to its original condition before application of the FRP composite. The columns were in a much better condition than the cap beam, and showed no evidence of corrosion. However, in order to ensure good bond of the FRP composite, they were also water washed prior to application of the FRP composite, as shown in Figure 4.



Figure 3. Cap Beam Repaired with Shotcrete



Figure 4. Water Washed and Cleaned Column

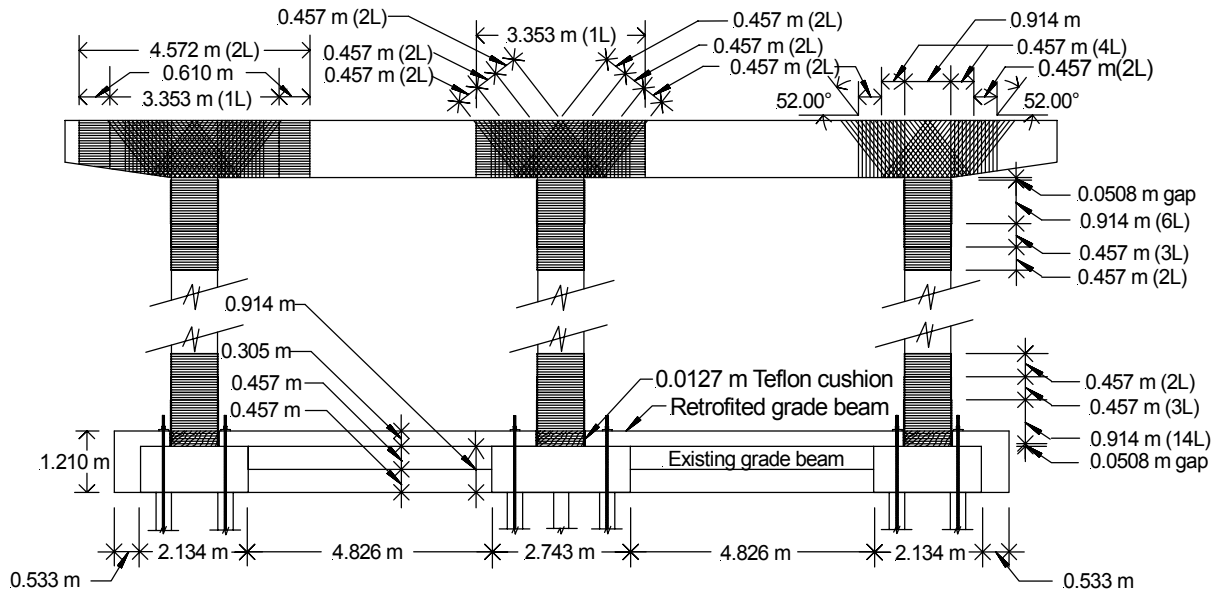
3. FRP Composite Design Considerations

Figure 5 shows the overall dimensions of Bent No. 6 and Figures 6 and 7 the carbon fiber reinforced polymer (FRP) composite retrofit design for Bent No. 6. The design shows three separate wraps per column, i.e. bottom, top, and column-cap joint. The bottom and top sections are mainly composed of 0-degree wraps. The cap however consists of +52, -52 and 90 degree wraps.

The design is based on 18" (457mm) wide carbon fabric. Hence to achieve 3 foot (914mm) wide wraps (shown in Figure 6), we used two 18" (457mm) wide fabric wraps, placed side-by-side. All the fabric for cap beam used 18" (457mm) wide fabric. The vertical straps use 6" (152mm) wide fabric. The 0-degree wraps in the cap beam hold the 52-degree joint wraps in place through a clamping mechanism. The 6" (152mm) straps (shown in Figure 7) hold the joint together by relieving the vertical column bars of the high tensile forces, and by providing a positive connection between the cap beam joint and the column.

The design shows steel girders present along the cap beam. The girder positions turned out to be incorrect in the field. As a result minor changes were made to accommodate this (included in Procedure section).

The goal of the seismic retrofit was to improve the displacement ductility of Bent No. 6 by a factor of two as compared to the as-is Bent No. 5. Structural analysis showed that the bent had deficiencies in the following areas: the confinement of the column lap splice region, the confinement of the plastic hinges, the column shear, the shear in the joint region, and the anchorage of the column longitudinal reinforcement into the cap beam. To address these issues, the bent and each element were analyzed and the structural retrofit using FRP composites was specified by University of Utah researchers.



Retrofit Details:

- 1) L = composite layers
- 2) All column composite layers are typical
- 3) East beam cap joint has 2 additional horizontal composite layers
- 4) Center beam cap joint has 1 additional horizontal composite layer

Figure 6. FRP Composite Design for Bent No. 6 – Part I

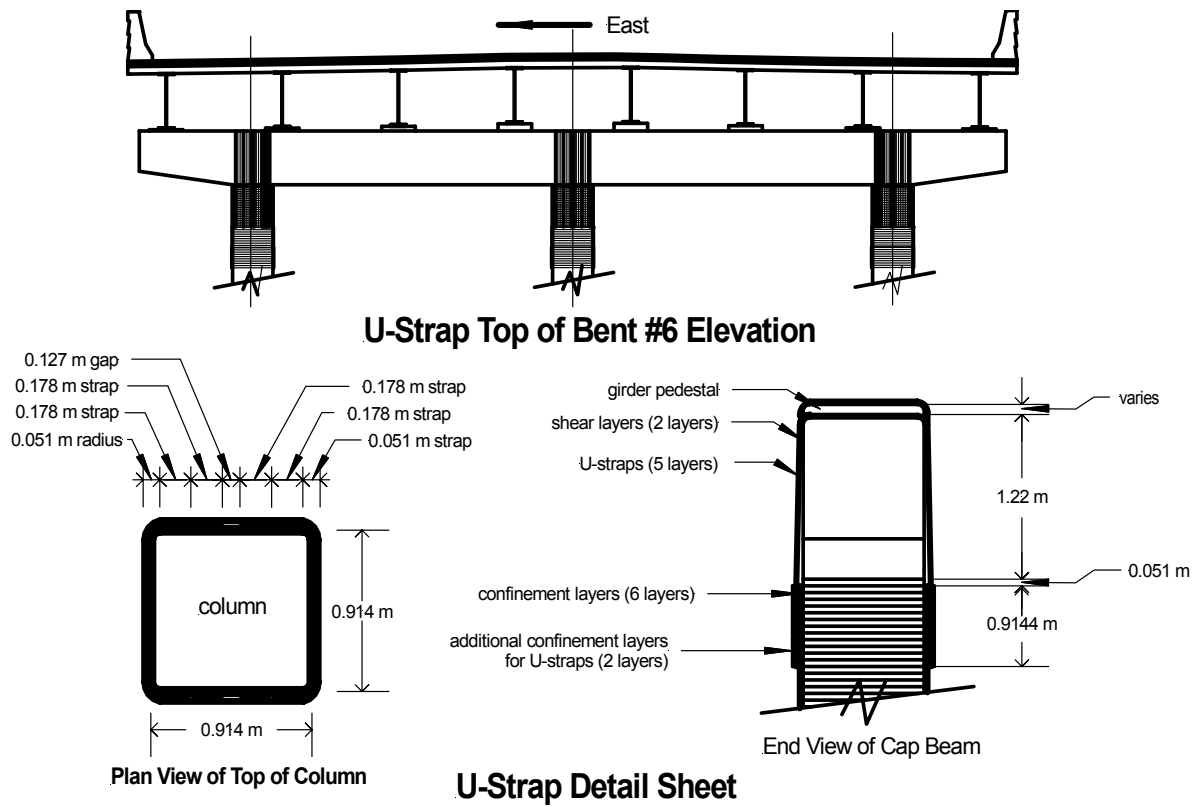


Figure 7. FRP Composite Design for Bent No. 6 – Part II

4. Procedures for Retrofitting Bent No. 6

Column Preparation

The first step for a successful retrofit job is to clean the concrete structure to ensure good adhesion between the adhesive and concrete. This was accomplished by using water jet blasting. Since the water jet was done one week before the columns were repaired, the surfaces had to be ground and brushed off to remove dust. The profiling material, Sikadur® 31 Hi-Mod, high strength structural adhesive, was used to patch large voids. All corners of the columns were rounded and smoothed using the grinders. After cleaning (as shown in Figure 8), patching and grinding, the columns were marked where the carbon fabric needed to be laid down. In the case of columns, the wrap started 2" (51mm) from the top of the footing and 2" (51mm) down from the column-cap joint. The application of Sikadur® 31 structural adhesive is demonstrated in Figure 9. The pattern layout procedure for both the columns and beam cap is shown in Figure 10.



Figure 8. Cleaning Column



Figure 9. Applying Profiling Material



Figure 10. Pattern Layout Prior to Repair

The final step in preparing the columns was to coat the area that would accept the carbon cloth with Sikadur® Hex 300 Impregnating Resin, as shown in Figure 11. This is the same resin that is used to impregnate the carbon cloth. The reason the resin is applied is to give the impregnated carbon cloth a better bonding surface. It should be noted that Sikadur® 31 structural adhesive was not used to facilitate bonding to the concrete substrate.



Figure 11. Base Resin Application

Once the base resin coat has been applied, the column is ready to accept the carbon FRP composite material. The material selected by Sika was SikaWrap® Hex 103C carbon fabric in combination with Sikadur® Hex 300 Impregnating Resin.

The carbon fabric for the columns was 18" (457mm) wide and came in roll form. The resin came pre-weighed from the factory in two containers, one for part A and the other for part B. There is sufficient free volume in container A to accept all the contents of container B.



Figure 12. Mixing "A" & "B"

The contents of container "B" are poured into container "A" and the mixture is mixed for 3 to 4 minutes, as shown in Figure 12. This is the manufacturer's recommended procedure and corresponds to typical industry practices.

Once the resin has been mixed, the carbon fabric is impregnated. Sika used a saturation machine for this purpose, as shown in Figure 13. The saturator is a machine with two rollers that combines the resin and fabric. This method is very efficient. The saturator is calibrated for the resin viscosity, fabric weight, temperature, and fabric width. The fabric is loaded on a let-off and passed through the two saturation rolls. This action forces the resin into the fabric, a process termed impregnation as shown in Figure 14, and eliminates the possibility of having dry fibers appear in the finished FRP composite jacket. The machine is manually operated and is suited for a construction environment. Once the desired length of fabric has been saturated, the material is cut off using scissors, as shown in Figure 15.

The impregnated carbon fabric is then taken to the column and applied. The application takes place on the column that has already had a layer of Sikadur® Hex 300 Impregnating Resin applied to the surface. It is important to note that Sika suggests that the layer of Sikadur® Hex 300 Impregnating Resin is still wet when applying the first layer. The material was cut to a length sufficient to apply 5 layers in one continuous application step. This technique is typically referred to as a "jelly roll", as shown in Figure 16. The material was applied to one column at first that served as a training column then it was applied to the other two columns by two different teams.



Figure 13. Saturation Unit

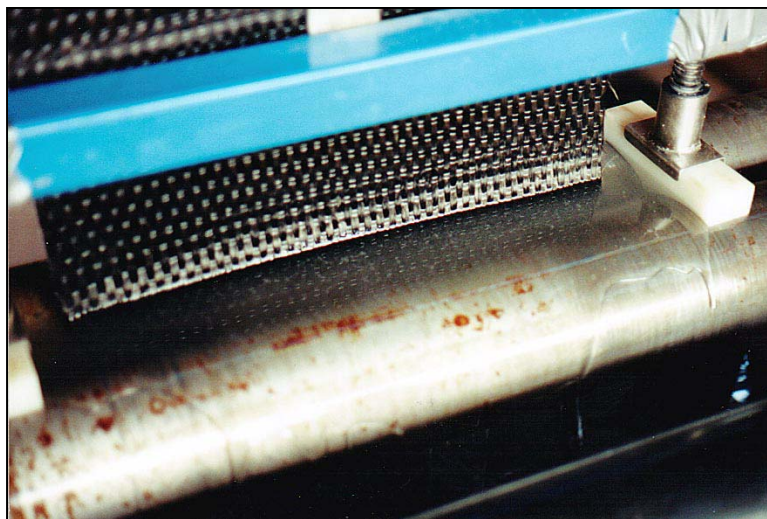


Figure 14. Impregnation Process

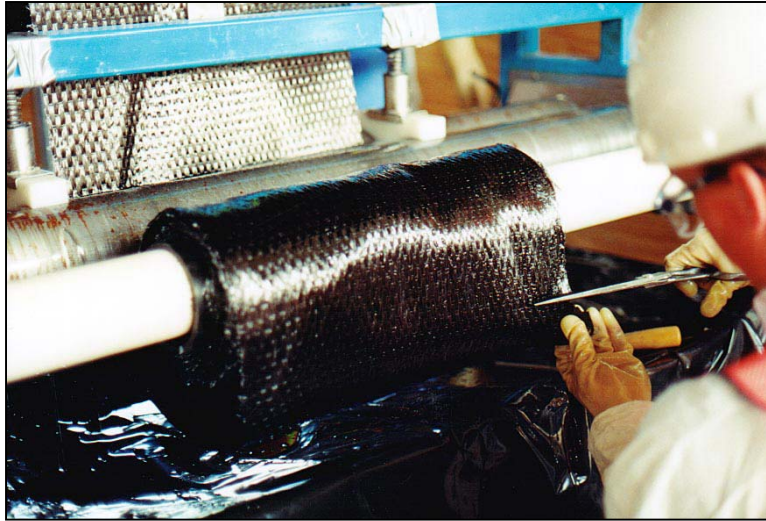


Figure 15. Cutting Material to Size



Figure 16. Applying Material in "Jelly Roll" Fashion

The "jelly roll" method, although saving time, may have been partially responsible for some void problems that occurred in a later phase of this project. These voids, when they were detected during application of the FRP composite, were worked out using various hand tools as shown in Figure 17.



Figure 17. Working Voids Out

This method of application was continued until the lower portions of the columns were completed. Once this had been accomplished, the upper sections of the three columns were completed according to the design, as shown in Figure 18.



Figure 18. Applying Carbon to Upper Portion of Column

The installation on the lower and upper portion of the columns was done in accordance with the manufacturer's instructions. The first 5 layers were applied on one day and then allowed to cure. On the second day, the remaining layers were to be applied.

On the second day, the lower portions of the columns were inspected prior to the installation of the remaining layers of carbon. Upon inspection it was noticed that there were a number of voids found in the jackets particularly on the east and west columns, which were exposed to direct sunlight during cure. These voids were of various sizes, from small (the size of a quarter) to very large ranging from 20 in² to 30 in² (0.26 m² to 0.58 m²), as shown in Figure 19. This defect had to be addressed prior to proceeding with the remaining wraps of carbon cloth.



Figure 19. Voids in Column Jacket

The void areas were repaired using the following procedure:

- Locate the void areas.
- Drill ~ 1/4" diameter hole in the lower and upper portions of the void.
- Inject Sikadur® Hex 300 Impregnating Resin into the voids until it flows out the top hole (Figure 20).
- Plug the lower hole with Sikadur® 31 (Figure 21).
- Allow the resin to cure.



Figure 20. Injecting Resin Into Void



Figure 21. Profiling Material Patching Lower Hole

The void problem required 8 additional man-hours to repair. This must be avoided in future applications because of the cost that will be incurred by the contractor.

There are several possible reasons for the voids forming in the jacket. It should be noted however, that voids in a confinement application such as the column, are not as detrimental as when bond is important, as in the case of the beam cap. However, the voids delay the participation of the FRP composite in the confinement effect and that is not desirable. The voids are also unsightly, and every effort should be made to avoid them.

Possible reasons for void formation are:

- Jelly-roll installation process. This has been noted on other retrofit jobs.
- The resin, Sikadur® Hex 300, has a long gel and cure time. This could cause the fabric to "sag" under its own weight and cause layers to separate.
- Normally, flat surfaces, even on square columns, are treated with an adhesive prior to installation of the carbon material. In this case, however, a structural adhesive (as the first layer on the concrete) was not used.
- Out-gassing from the concrete.
- Direct exposure to the sun during cure.
- Grinding was the surface preparation vs. sandblasting which would be preferable.
- Sikadur® Hex 306, which is a heavier, more thixotropic epoxy might have sealed the pores of the concrete better thus reducing out-gassing from the concrete.
- The use of a cementitious or epoxy leveling mortar on the columns before wrapping will reduce or eliminate concave or low spots and out-gassing of the concrete.

Things to do in future applications:

- Use of the fabric saturator is essential.
- Use of cementitious or epoxy leveling mortar on concrete before wrapping.
- Sandblast surfaces to receive FRP composite wrap.
- Use of Sikadur® Hex 306 epoxy.
- Apply fewer wraps at a time.
- Shading FRP composite from direct sunlight during cure.
- Covering FRP composite with a cementitious or acrylic coating to protect it from ultraviolet light damage for long-term performance.

In order to assure the highest quality FRP composite jacket installation, it is important for the contractor and the material supplier to adjust their installation procedure to avoid the formation of voids in the future.

Cap Beam Preparation

All loose concrete material was removed and shotcrete was applied to the surface prior to the following procedure. The first step for a successful cap beam retrofit job is to clean the concrete structure to ensure good adhesion between the adhesive and concrete. This was accomplished by grinding the entire surface of the shotcrete that would receive the FRP composite material. The profiling material, Sikadur® 31 Hi-Mod, high strength, structural adhesive was used to patch large voids and fill uneven spots, as shown in Figure 22. Sikadur® 31 Hi-Mod, high strength, structural adhesive was also used as the prime (coat between the concrete and the first layer of carbon material) layer on the cap beam, as shown in Figures 23 and 24. All corners on the cap beam were rounded and smoothed using grinders. After cleaning, patching, and grinding, the cap beam was marked to indicate the placement of the carbon fabric.

The procedure for the cap beam differs from that of the column wrap. All steps including marking the columns, applying the adhesive, carbon and resin are the same. The only difference is in wrapping the 52 degree and 90 degree pieces around the cap. The +52 degree pieces are laid down first. The fabric is started from the mid-face of cap at top to mid-face of cap at bottom. The -52 degree fabric is then laid down overlapping the previous +52 degree piece. Once the 52 degree pieces are in place, the 90-degree hoops are wrapped as close to the joint as possible. These start and end at the mid-face of the bottom of cap. The thin 6" (152mm) straps are then placed as shown in the design. The straps start on the column, wrap all the way across the cap and then end on the opposite face of the column. The final two layers of carbon are placed around the straps on the column surfaces to secure the straps in place.



Figure 22. Profiling Material Applied to Fill Uneven Spots



Figure 23. Profiling Material Applied as Prime Layer to Cap Beam

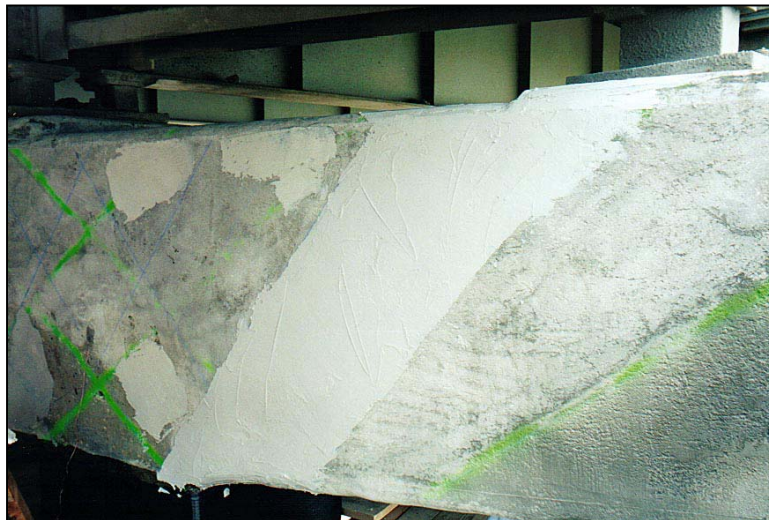


Figure 24. Profiling Material Applied to Bottom of Cap Beam

The application steps in the sequence of pictures shown in Figures 25 to 31 are very important. The adhesion between the concrete substrate and the FRP composite material is vital to the overall strength of the system. The loads must be between the concrete and the FRP composite through this layer. If there are any voids on

the flat surfaces the loads will not be transferred properly, thus reducing the overall strength of the system.



Figure 25. 52 Degree Layer Being Applied



Figure 26. 52 Degree Layer In Place



Figure 27. 90 Degree Layer Being Applied



Figure 28. 90 Degree Layer In Place



Figure 29. Application of Six Inch Strips (U-straps)



Figure 30. Six Inch Strips (U-straps) In Place



Figure 31. Final Layer Applied to Column to Tie 6 in. Strips (U-straps) Down

Avoid starting from the corners. While wrapping the first layer of carbon, one person lays the fabric down and a second person consolidates using a metal roller. This ensures uniform bond to adhesive and minimum air pockets. Make sure there is a 6" (152mm) overlap at the end. The use of a manlift to move materials from bottom to top is recommended in this operation.

The environment and surroundings were excellent for this job. The temperatures were ideal. It rained unexpectedly only one day. In case of rain, make sure the surface is completely dry prior to applying any epoxy.

6. Safety

Lay out the plastic to avoid creating a mess on the ground and columns. Reiterate safety procedures to everyone. Assign people for each column: Mixer, Resin applicator, Adhesive applicator and Impregnator/Consolidator, Safety officer/Supervisor/Quality assurance.

Every person on the crew went through UDOT safety training. In addition, safety meetings were held at the beginning of each shift. Each project leader was responsible for the safety of his own crew.

7. Conclusions

The retrofit of the South Temple Bridge on I-15 was accomplished in a timely manner. There was little waste of material and time. The process of retrofit using FRP composite materials has now been demonstrated three times in Utah, each time increasing the knowledge base for the introduction of this new technology.

In all cases, the viability of FRP composites from a constructability standpoint has been successfully demonstrated. In this particular application, the use of the saturation unit proved to be very valuable. The quality of the impregnation was improved from the 1998 installation with the use of this device. The impregnation of the fabric was complete and there was no evidence of dry fibers. In future applications it is suggested that UDOT require the use of such a device or insist on pre-impregnated materials.

For all rectangular or square columns it is suggested that an epoxy adhesive layer or cementitious leveling mortar be applied to the surface prior to the application of any FRP composite wrap. This will lessen the chances for the formation of voids and assure a good concrete / FRP composite bond which is vital in transferring the loads from the concrete to the FRP composite.

APPENDIX

Labor and Labor Analysis

The man-hours used, the labor analysis by hour and by a percentage of the total are given in Table A1 and Figures A1 and A2.

Table A1. Man-hour Breakdown

Date/Task	6/14/99	6/15/99	6/16/99	6/17/99	6/18/99	Total
Scaffold Work	3					3
Pattern Layout	4					4
Column Prep	10					10
Cap Beam Prep	22.5					22.5
Column Wrap		106.5	91.5	36		234
Cap Beam Wrap				47	39	86
Void Injection			7			7

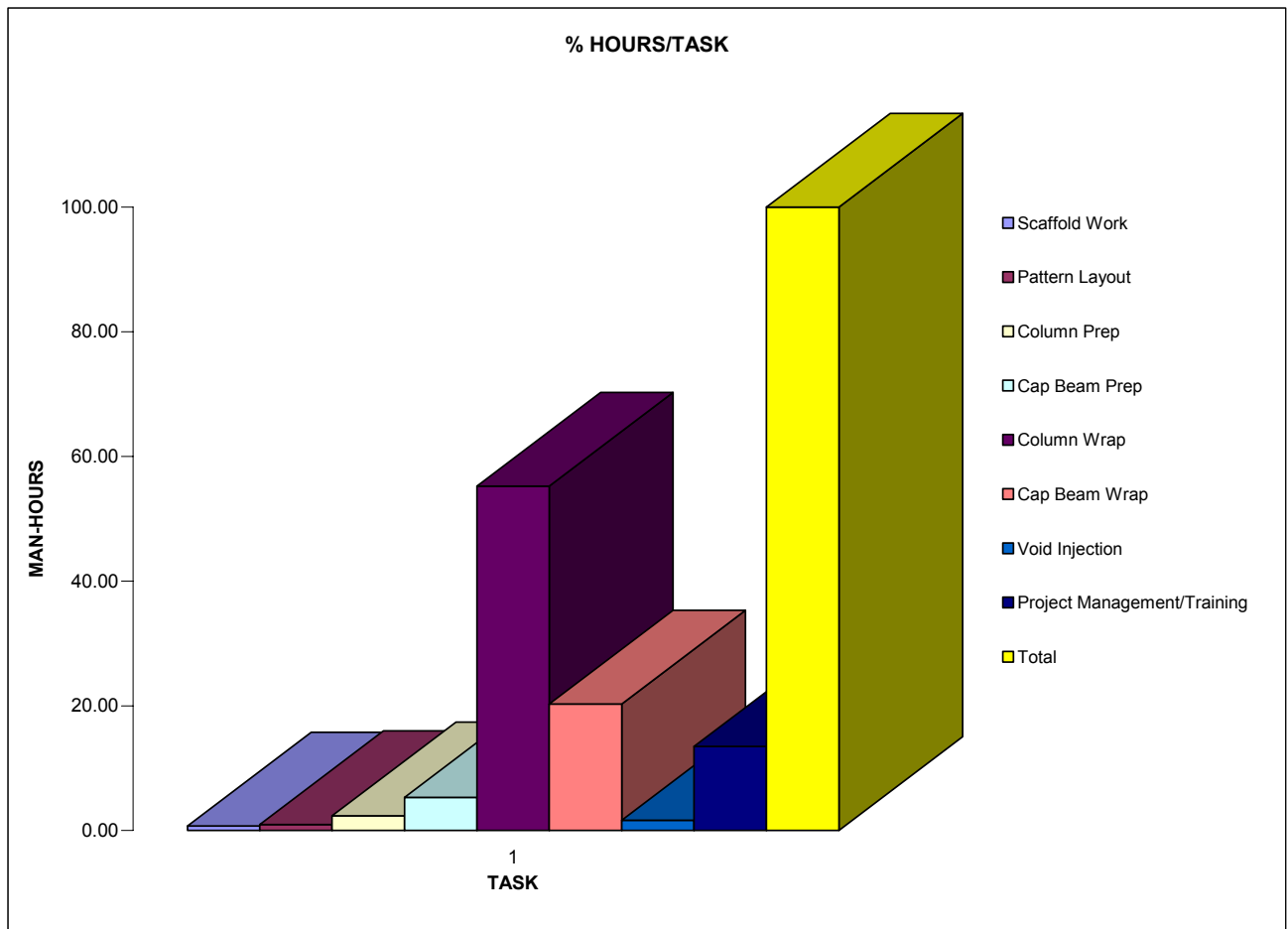


Figure A1. Labor Analysis by Percentage of Total Man-Hours

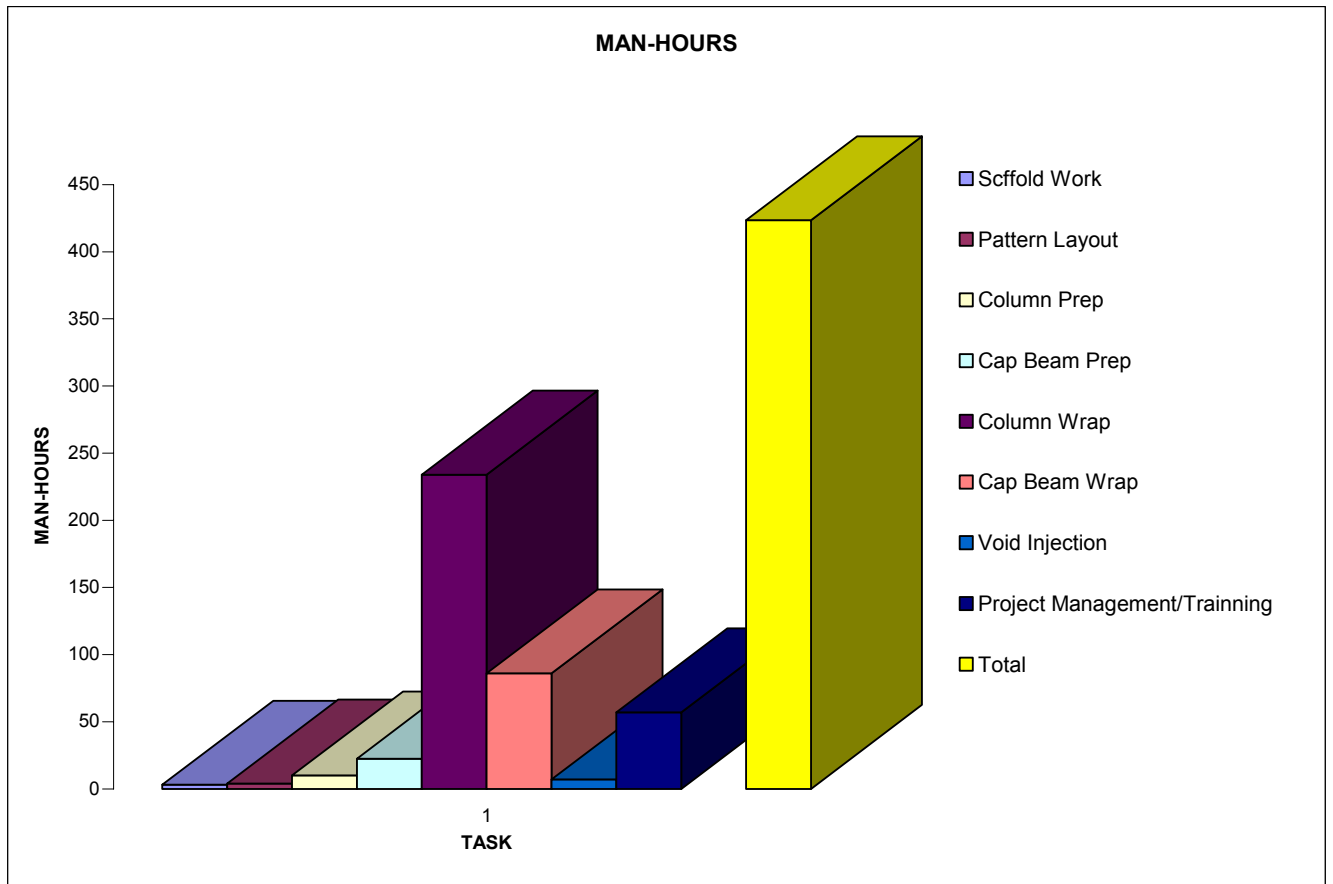


Figure A2. Labor Analysis by Man-Hours

Material and Material Analysis

Sika Corporation supplied the materials for this project. The materials supplied for the project were:

Sikadur® 31 High-modulus, Structural Epoxy Adhesive

Sikadur® Hex 300 Impregnating Resin

Sikawarp® Hex 103C Carbon Fabric

In addition to the materials supplied by Sika Corporation, Hydrotech supplied the saturation machine and labor for the installation.

Table A2 gives a breakdown of the materials and their usage.

Table A2. Breakdown of Materials and Their Usage

Resin System	Lot Numbers	Column Total	Cap Beam Total	Sq. Ft. Column	Sq. Ft. Cap Beam
Sikadur® Hex 300 Impregnating Resin A	300A042299-1	17 Units	10 Units		
Sikadur® Hex 300 Hardener B	300B051999-2				
Density Sikadur® Hex 300 Impregnating Resin A	36.23 lb./ 2.78 gal/Unit	615.91	362.3		
Density Sikadur® Hex 300 Hardener B					
Total (Lbs.)		615.91	362.3		
Profiling Compound					
Sikadur® 31 Hi-Mod Gel A	A90002M	1	10		
Sikadur® 31 Hi-Mod Gel B	M80032M				
Density Sikadur® 31 Hi-Mod Gel A	29.5 lb./ 2 gal/Unit				
Density Sikadur® 31 Hi-Mod Gel B					
Total (Lbs.)		29.5	295		
Fabric					
SikaWrap® Hex 103C	9C60116A (ft. x 18" Width)	2601	480	3901.5	720
	9C60116A (ft. x 7" Width)		1080		629.64
Total (Ft. Sq.)				3901.5	1349.64
Density SikaWrap® Hex 103C (Oz/sq. yd.)	18				
Weight of SikaWrap® Hex 103C Used (Lbs.)				487.69	168.71
Total (Lbs.)				487.69	168.71

Prior to the retrofit process, the University of Utah had the columns prepared for the wrap. This included hydro-blasting and rebuilding the surfaces of the cap beam with shotcrete. The costs associated with this phase of the project are shown in Table A3.

Table A3. Costs Associated with Hydro-blasting

Operation	Man hours	Cost
Shotcrete	300	\$10,000.00
Water Blast	67	\$6,000.00
Scaffold		\$2,000.00

Other miscellaneous charges incurred for the project are listed in Table A4.

Table A4. Miscellaneous Costs

Equipment	Time	Cost
Man Lift	One week	\$850.00
Trash Removal	One week	\$150.00
Toilet		\$70.00

Tools Used

The following tools were used during the project:

Project plans	Hammers
Safety gear	Tape measure
Life lines	Fabric saturator
Connection to life lines	Sikadur 31
Harness	Sikadur Hex 300/306
Lanyards	SikaWrap Hex 103C
Hard hats	
Safety glasses	
Safety shoes	
Vest with reflective markings	
Black plastic 6ft. wide, 100 ft. long	
Water	
Respirators	
MSDS and certificates of all materials	
Manlift	
Generator	
Mixing equipment for adhesive (drill and mixing blades)	
Mixing equipment for the resin (drill and mixing blades)	
Cutting tool	
Neoprene latex gloves (XL)	
Tyvek body suits	
Paint pails	
Acetone	
Squeegees with handles	
Mixing buckets	
Flat sticks to mix/scoop adhesive from buckets	
Trowels to apply adhesive	
Garden trowels to scoop adhesive from buckets	
Scissors	
Knives	
Steel rollers	
Tarps	
Wire brushes	
Rags	
Extension cords	
Workbenches	